EXCITATION AND ATTENUATION OF REGIONAL WAVES, AND MAGNITUDE DEPENDENCE OF PN/LG RATIOS IN EASTERN EURASIA

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Sponsored by The Defense Threat Reduction Agency
Contract No. DSWA01-98-1-0006 and DSWA01-98-1-0009

ABSTRACT

In the past one and half years I have been processing large amount of regional/teleseismic data from IRIS, CDSN, GBA, Kyrghizstan and Kazakhstan network stations in eastern Eurasia. Fourier spectra of Pn, Lg and Pg waves were computed for many events/paths to study characteristics of seismic sources and path attenuations. Estimations of source spectral parameters and path attenuation were difficult for all wave types. I have used various methods to tackle the difficulties, including the standard two-station method for Q measurement, the reversed two-station method of Chun et al. (1987) for Q measurement, the empirical Green's function method for measuring source rise times, and the simultaneous Bayesian inversion method for source-path spectral parameters by Xie (1993, 1998, 1999).

It is well known that seismic source parameters, such as magnitude, seismic moment and corner frequency tend to scale with one another. Xie and Patton (1999) obtained details of these scalings for each wave types (Pn and Lg), and source types (underground nuclear explosions and earthquakes) in central Asia. These scalings, and an spectral overshoot in explosion-excited Pn and Lg waves, make the Pn/Lg spectral ratios from explosions differ from those from earthquakes in a frequency-dependent manner. For a given event size, there is a frequence band in which the Pn/Lg spectral ratios from both source types differ the most, resulting in an optimal frequency band for the ratios to be used for a discrimination purpose. This optimal frequency band is dependent on the corner frequencies derived using Pn and Lg. For events with smaller magnitudes or seismic moments, the Pn and Lg corner frequencies become higher, causing the optimal frequency band to shift higher.

Until recently, the analyses of explosions in central Asia were conducted only for a limited magnitude range (about 5.0 to 6.0). A new analysis have been conducted using data from a large Lop Nor explosion (mb=6.6 on May 21, 1992) and a small Kazakhstan explosion (mb=3.8 on Aug. 22, 1998). Special efforts have been made to make Q estimates in this and previous analyses consistent with each other. The new analysis validates the previously proposed source spectral scaling relationships and the magnitude dependence of Pn/Lg spectral ratios in a wider magnitude range. Observed Pn/Lg ratios from the two new explosions clearly support the magnitude dependence of the Pn/Lg ratio. In particular, they show that attempts of discriminating explosions from earthquakes using Pn/Lg spectral ratios, when the magnitude dependence is ignored, may fail. Since the spectral scalings and spectral overshoot are expected to hold for other high-frequency phases, a magnitude dependence should also be present for other types of phase spectral ratios.

Key Words:Seismic Sources, Q, Eastern Eurasia, Explosion Discrimination, P/Lg ratios

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Excitation And Attenuation Of Regional Waves, And Magnitude Dependence Of PN/LG Ratios In Eastern Eurasia**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lamont-Doherty Earth Observatory of Columbia University,61 Route 9W,Palisades,NY,01964**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 22nd Annual DoD/DOE Seismic Research Symposium: Planning for Verification of and Compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) held in New Orleans, Louisiana on September 13-15, 2000, U.S. Government or Federal Rights.

14. ABSTRACT
See Report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

OBJECTIVE

There are two ultimate objectives of this research: (1) We wish to quantify path attenuation of regional waves in continental areas, such as Eurasia, by developing digital, tomographic Q maps. (2) We wish to quantify the difference in the excitations of various regional waves, so that we may achieve better, quantitative understanding and criterion of the P/Lg spectral ratio discriminant of explosions. There proposed research is composed of several tasks. The first is to further improve the inverse method for simultaneous determination of source seismic moment (M_0), corner frequency (f_c) and path-variable Q_0 and η (Q at 1 hz and its power-law frequency dependence, respectively) using regional wave spectra. The second task is to apply the improved inverse method to Lg, Pn, Pg and Sg spectra from many earthquakes and explosions in Eurasia to estimate source M_0, f_c and path Q_0, η. The third task is input the measured Q values to a computerized tomographic algorithm, to obtain laterally varying Q maps for Lg and other regional waves. The fourth task is analyze source spectral scaling and other source spectral characteristics of seismic events, such as the amount of spectral overshoot of explosions, to explore when, how and why the P/Lg spectral ratios can be used to discriminate explosions from earthquakes.

This research provides important input to the implementation of a Comprehensive Nuclear-Test-Ban Treaty. The tomographic Q maps can be used for the calculation of source spectral characteristics of any future seismic event to infer the nature and size of the event. These Q maps can also be used for estimating the detection threshold of the existing seismic stations located within the area studied. The source spectral behavior inferred from this study will help to understand if, when and how the P/Lg amplitude ratio can be used to discriminate explosions from earthquakes.

RESEARCH ACCOMPLISHED

Processing of Lg, Pg and Pn spectra in eastern Eurasia

In the past one and half years I have been processing large amount of regional/teleseismic data from IRIS, CDSN, Kyrghizstan, Kazakhstan and GBA network stations in eastern Eurasia. Fourier spectra of Pn, Lg and Pg waves were computed for many events/paths to study characteristics of seismic sources and path attenuations. Fig. 1 shows the path coverage by these spectra.

The spectra have been used to derive path-variable Q at 1 Hz and its power-law frequency dependence, as well as source spectral parameters for each wave type. It is well known that estimations of source spectral parameters and path Q were difficult. I have used various methods to tackle the difficulties, including (1) the standard two-station method for Q measurement, (2) the reversed two-station method of Chun et al. (1987) for Q measurement, (3) the empirical Green's function method for measuring source rise times which can be converted to corner frequencies, and (4) the simultaneous Bayesian inversion methods for source-path spectral parameters by Xie (1993, 1998, 1999). Examples of applications of methods (2), (3) and (4) are shown in Figs. 2 through 4.

The magnitude dependence of Pn/Lg ratios

Xie and Patton (1999; here after referred to as XP99) developed source spectral scaling relationships for the excitations of Pn and Lg by underground nuclear explosions and

earthquakes in central Asia. Interesting features of these source spectral scalings include that (1) for explosions, seismic moments estimated using Pn are systematically larger than those estimated using Lg, (2) for both explosions and earthquakes Pn corner frequencies are systematically higher, by a factor of 3-4, than the Lg corner frequencies at the same moment level; (3) both Pn and Lg excitations by explosions exhibit spectral overshoot, whose effect appears to be more pronounced for Pn than for Lg. These features make the Pn/Lg spectral ratios from explosions differ from those from earthquakes at any fixed magnitude level in a frequency-dependent manner. As shown in Figs. 11 and 12 of XP99, at lower frequencies the Pn/Lg ratios from explosions tend to be higher than those from earthquakes at the same magnitude, but the difference can be relatively small. In a intermediate frequency range the Pn/Lg ratios from both explosions and earthquakes grow with frequency, but the growth is faster for the ratios from explosions than those from earthquakes. As a result, the Pn/Lg ratios from the two source types become more separated. Beyond certain high frequency limit the Pn/Lg ratios from both source types stop to grow, and the separation remain roughly unchanged with increasing frequency. Therefore there is a frequence band in which the Pn/Lg spectral ratios from explosions differ the most from those from earthquakes, resulting in an optimal frequency band for the ratios to be used for a discrimination purpose. This optimal frequency band is dependent on the corner frequencies derived using Pn and Lg. For events with smaller magnitudes or seismic moments, the Pn and Lg corner frequencies become higher, causing the optimal frequency band to shift higher.

A limitation of the work by XP99 is that the explosions used only cover a limited magnitude range (about 5.0 to 6.0). A new analysis have been conducted using data from a large, "megaton" Lop Nor explosion (mb=6.6 on May 21, 1992) and a small Kazakhstan explosion (mb=3.8 on Aug. 22, 1998). Fig. 5 shows locations of these two explosions. Q values have been obtained by XP99 for paths between the Lop Nor test site and KNET stations, and for the two-station path between stations MAK and KURK. The latter path runs very close to the path between the Kazakhstan explosion and station MAK in Fig. 5. Therefore I can use the Q values obtained in XP99 as a priori knowledge to inversions of the two new explosions, and avoid complications caused by inconsistent path Q corrections.

I obtained M_0, f_c values for Pn and Lg from both new explosions. Figs. 6 and 7 show the new scalings developed by adding these new values:

$$\log M_0 = 9.70(\pm 0.25) + 1.13(\pm 0.04)\ m_b \quad \text{for } Pn \text{ } from\ explosions, \tag{1}$$
$$\log M_0 = 9.26(\pm 0.45) + 1.12(\pm 0.07)\ m_b \quad \text{for } Lg \text{ } from\ explosions; \tag{2}$$
$$\log M_0 = 18.16(\pm 0.36) - 4.33(\pm 0.44) \log f_c \quad \text{for } Pn \text{ } from\ explosions; \tag{3}$$
$$\log M_0 = 15.18(\pm 0.22) - 3.80(\pm 0.26) \log f_c \quad \text{for } Lg \text{ } from\ explosions. \tag{4}$$

Note scaling relationships in equations (1), (2), (3) and (4) differ only slightly from the respective scalings (equations (16), (17), (20) and (21)) in XP99, developed without the two new explosions. Thus the analysis of the new explosions validates spectral scaling relationships in XP99. In Fig. 8, I replot the statistically expected Pn/Lg spectral ratios for different source types and magnitudes over an generic central Asian path, first shown in XP99 (Fig. 12), and the observed Pn/Lg spectral ratios for explosions and earthquakes in XP99. The statistical simulation fits the observation very well. Pn/Lg ratios for the newly analyzed, "megaton" and 100-ton explosions are also shown in Fig. 8 (thick curves in grey). These ratios are the observed ratios corrected for the new path-avaraged Q values that differ from those of the generic path. As

predicted by the scaling relationships, the two new ratios are similar in shape to the previous ratios from explosions, but are shifted along the frequency axis toward lower frequencies and higher frequencies for the "megaton" and 100-ton explosions, respectively, owing to the lower and higher f_c values.

Interestingly, between 1 and 10 Hz the 100-ton ratio in Fig. 8 falls into the earthquake population of XP99 because of the magnitude dependence. This is a good example of how ignoring the magnitude dependence can cause a false event identification using the Pn/Lg spectral ratio.

CONCLUSIONS AND RECOMMENDATIONS

I have been processing spectra of Pn, Pg and Lg waves from numerous paths in eastern Eurasia. When complete, the spectra will be used to invert for path-variable Q values and source M_0 and f_c values for the events involved. These will be used for tomographic regionalizations of Q, and for deriving or modifying source scaling relationships for explosions and earthquakes.

New analysis of a large, "megaton" and a small, hundred-ton explosions validated the source spectral scalings for explosions by Xie and Patton (1999) in a much wider magnitude range, and confirmed the magnitude-dependence of Pn/Lg ratio from explosions. I have demonstrated clearly that attempts of discriminating explosions from earthquakes using Pn/Lg spectral ratios, when the magnitude dependence is ignored, may fail. Since the spectral scalings and spectral overshoot are expected to hold for other high-frequency phases, a magnitude dependence should also be present for other types of phase spectral ratios in central Asia. At least for that region, future discrimination should incorporate the magnitude dependence. Future work using similar methodology is needed to see whether the magnitude dependence is a generally phenomenon in other continental areas.

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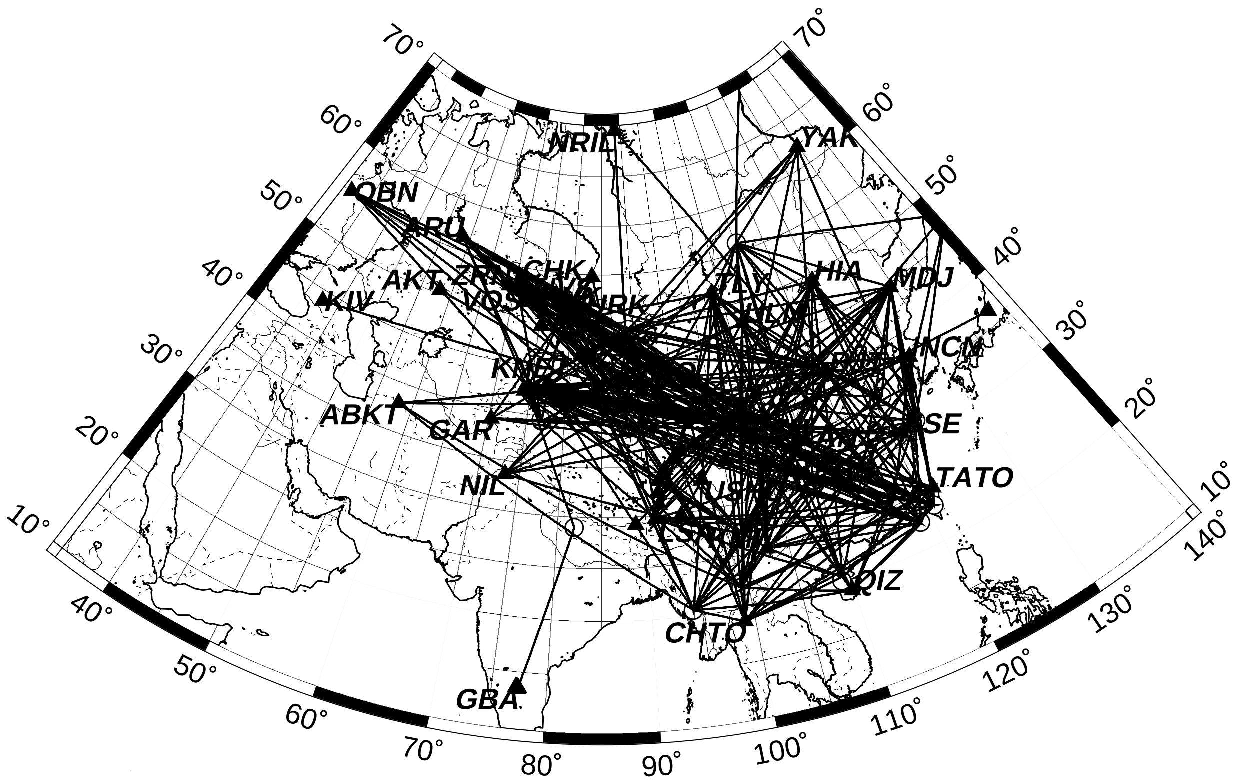

Fig. 1. Map showing path coverage by Lg, Pg and Pn spectra obtained in this study as of July, 2000.

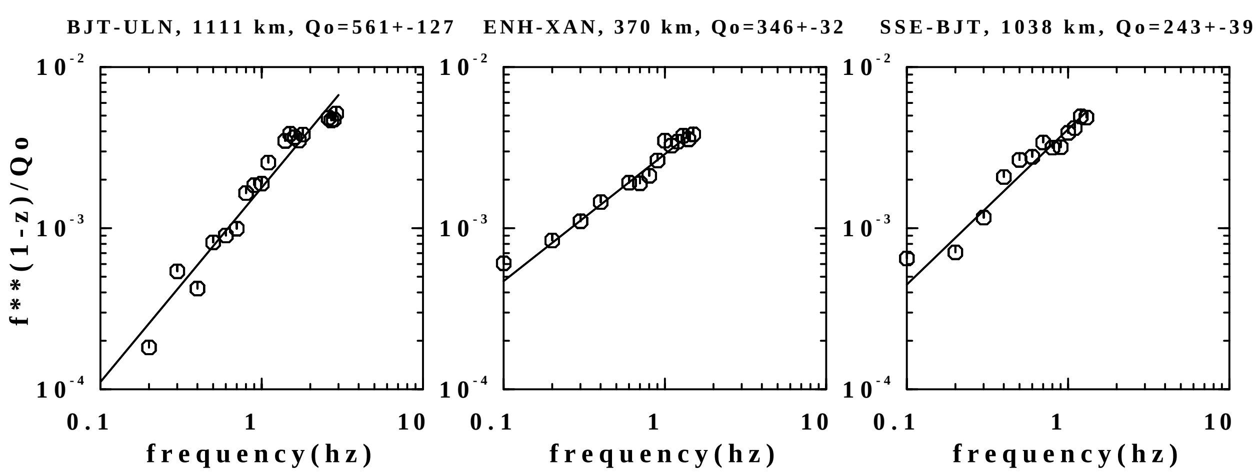

Fig. 2. Examples of inter-station Lg Q measurements using reversed two-station spectral ratios (Chun *et al.*, 1987). Station pair, inter-station distance and Q_0 values are indicated on the top of the panels.

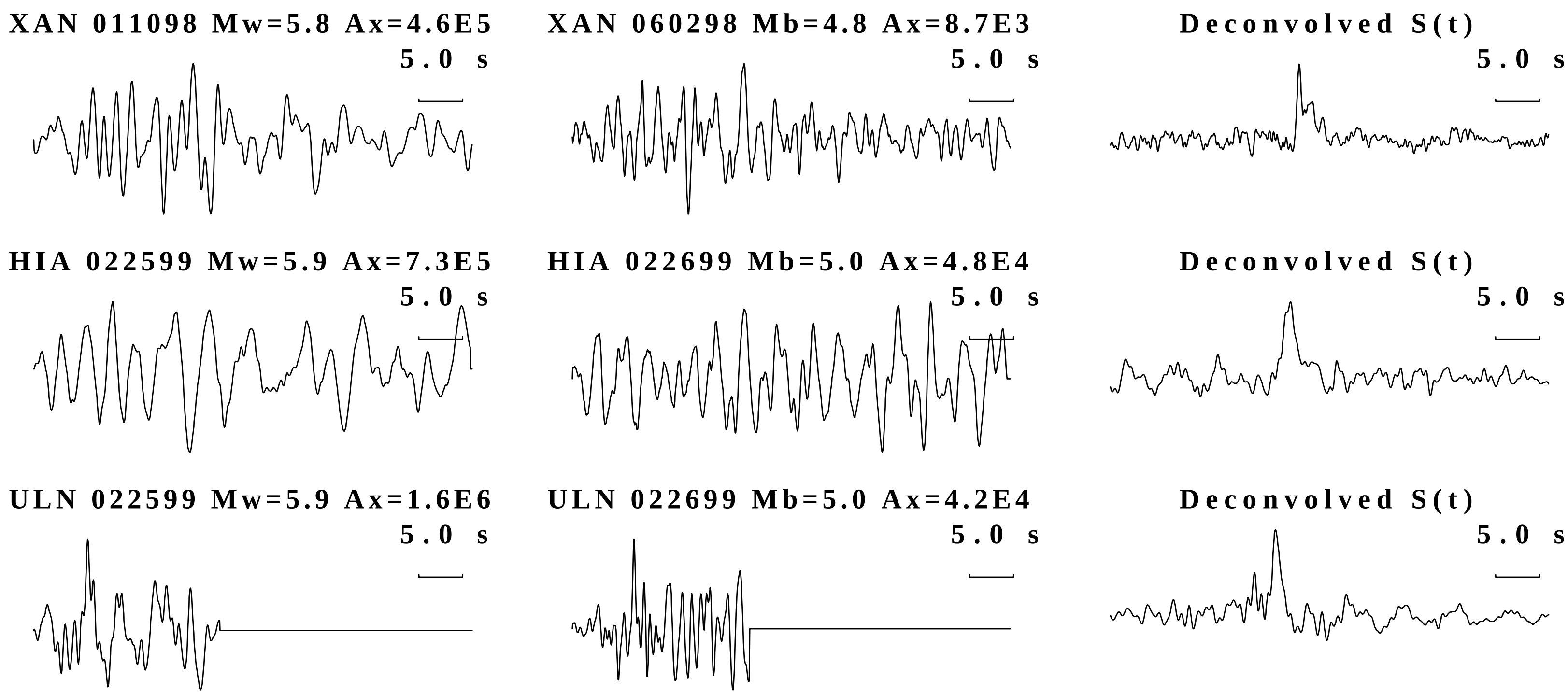

Fig. 3. Examples of the empirical Green's function (EGF) deconvolution. Each row shows Lg waveforms from a pair of large and small (EGF) events, observed at the same station (left and middle traces, respectively), and the deconvolved trace (right trace) from which a rise time can be measured. Station name, event date, event M_W or M_b and maximum amplitude in digital count are indicated on the top of the Lg waveforms. The epicentral distances involved are (from top to bottom rows): 956.4 km (XAN to 011098) 1087.4 km (HIA to 022599) and 445.1 km (ULN to 022599).

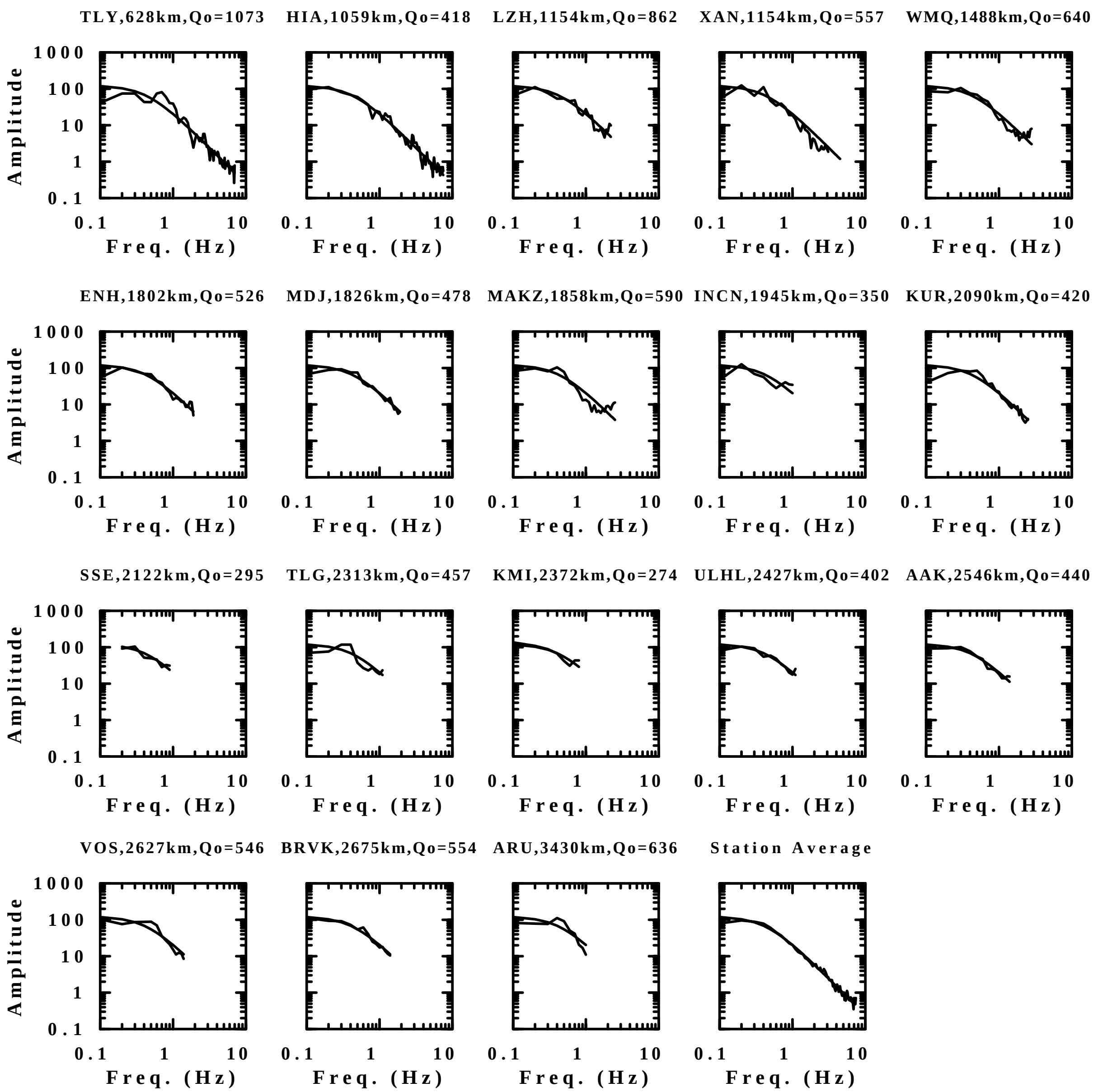

Fig. 4. Synthetic Lg source spectra for 18 broad-band stations recording the 09/24/98 Mongolian earthquake, versus the observed. The lower right panel is the station average. The synthetic spectra are calculated using the best-fit source model of ($M_0 = 1.26 \times 10^{17}$ N m, f_c = 0.44 Hz), obtained during the inversion with the Bayesian method (Xie, 1993, 1998, 1999). Station code, distance and Q_0 values obtained during the inversion are written on the top of the panels. The observed source spectra are ground motion spectra with the effects of path Q removed. The unit of the amplitude is the same as that of Figure 7 of Xie (1998).

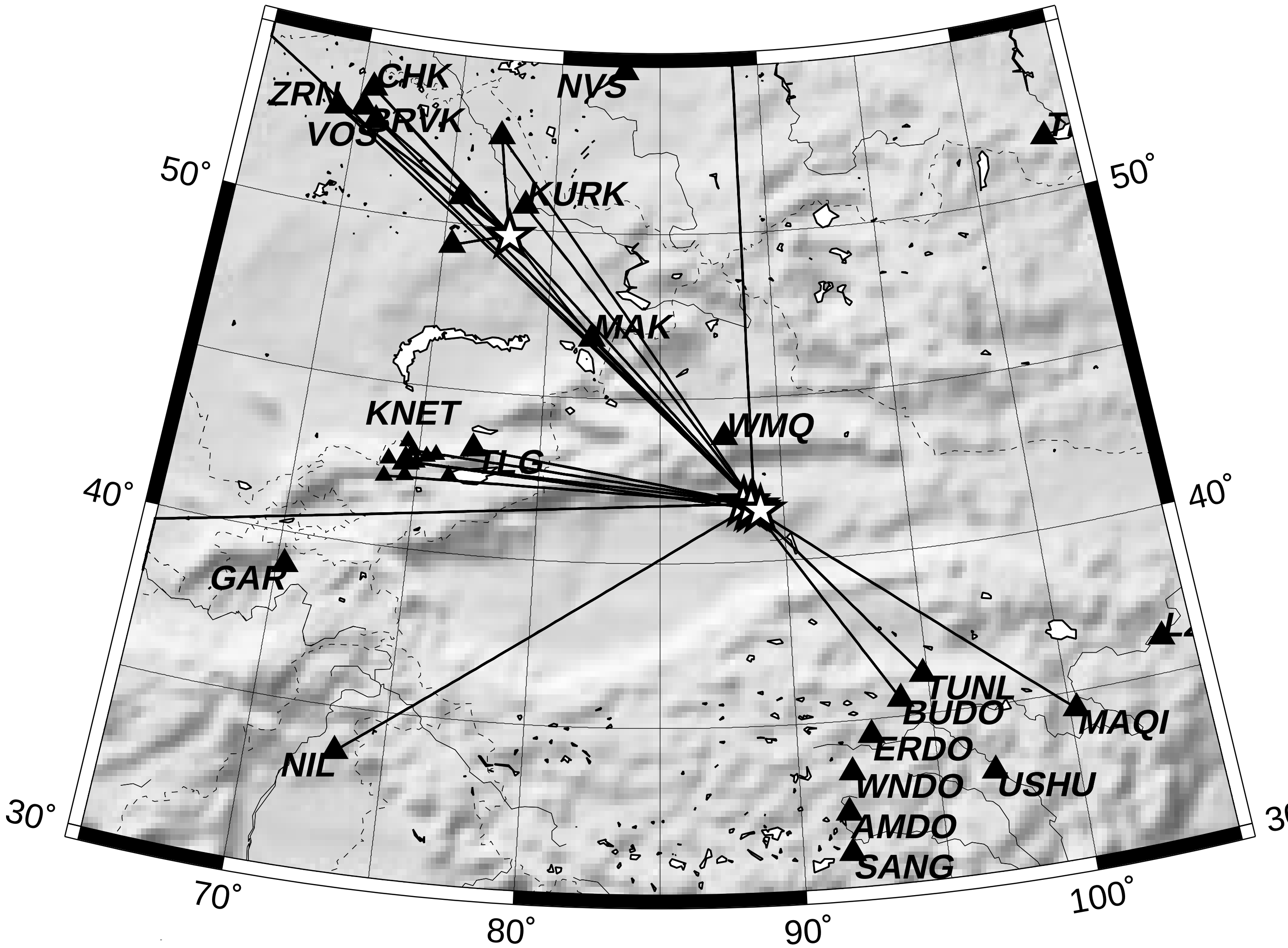

Fig. 5. Locations of the explosions in the Lop Nor and Kazakhstan test sites (stars) and recording stations (triangles). Stations in the southeast portion of the map are temporary stations deployed in the Tibetan Plateau Passcal experiment (1991-1992). Note that the path from the 100-ton, Kazakhstan explosion (star just south of station KURK) to station MAK runs very close to the two-station path between KURK and MAK in Xie and Patton (1999).

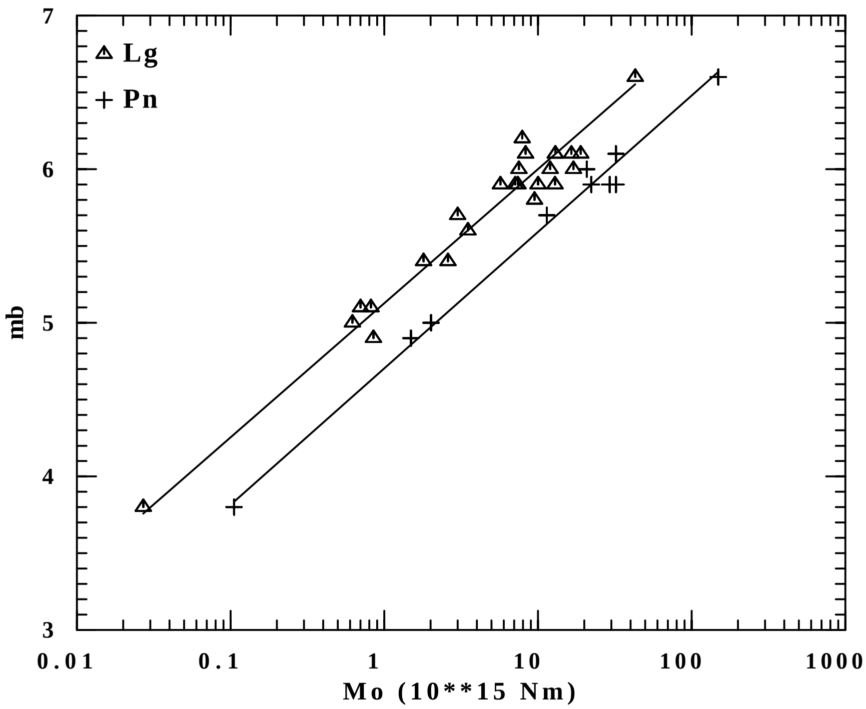

Fig. 6. m_b versus logarithm of M_0 for explosions in central Asia. Results for the 052192, "megaton" and 082298, 100-ton explosions are included, expanding the magnitude range of a previous study by Xie and Patton (1999, Fig. 7).

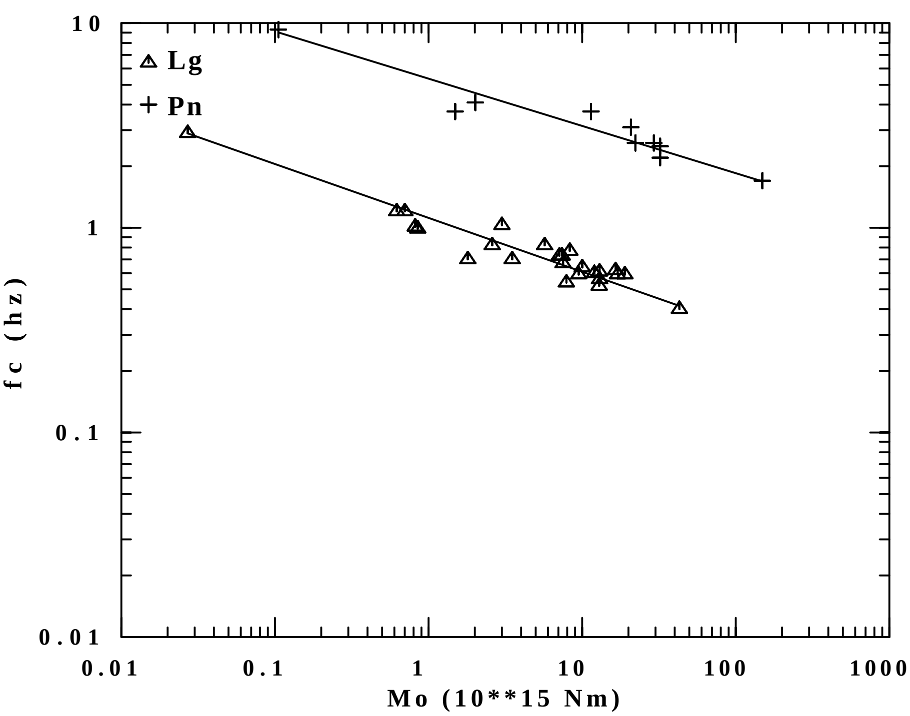

Fig. 7. f_c versus M_0 for explosions in central Asia. This figure is an expansion of Fig. 9 of Xie & Patton (1999) by adding M_0 and f_c values of the "megaton" and 100-ton explosions.

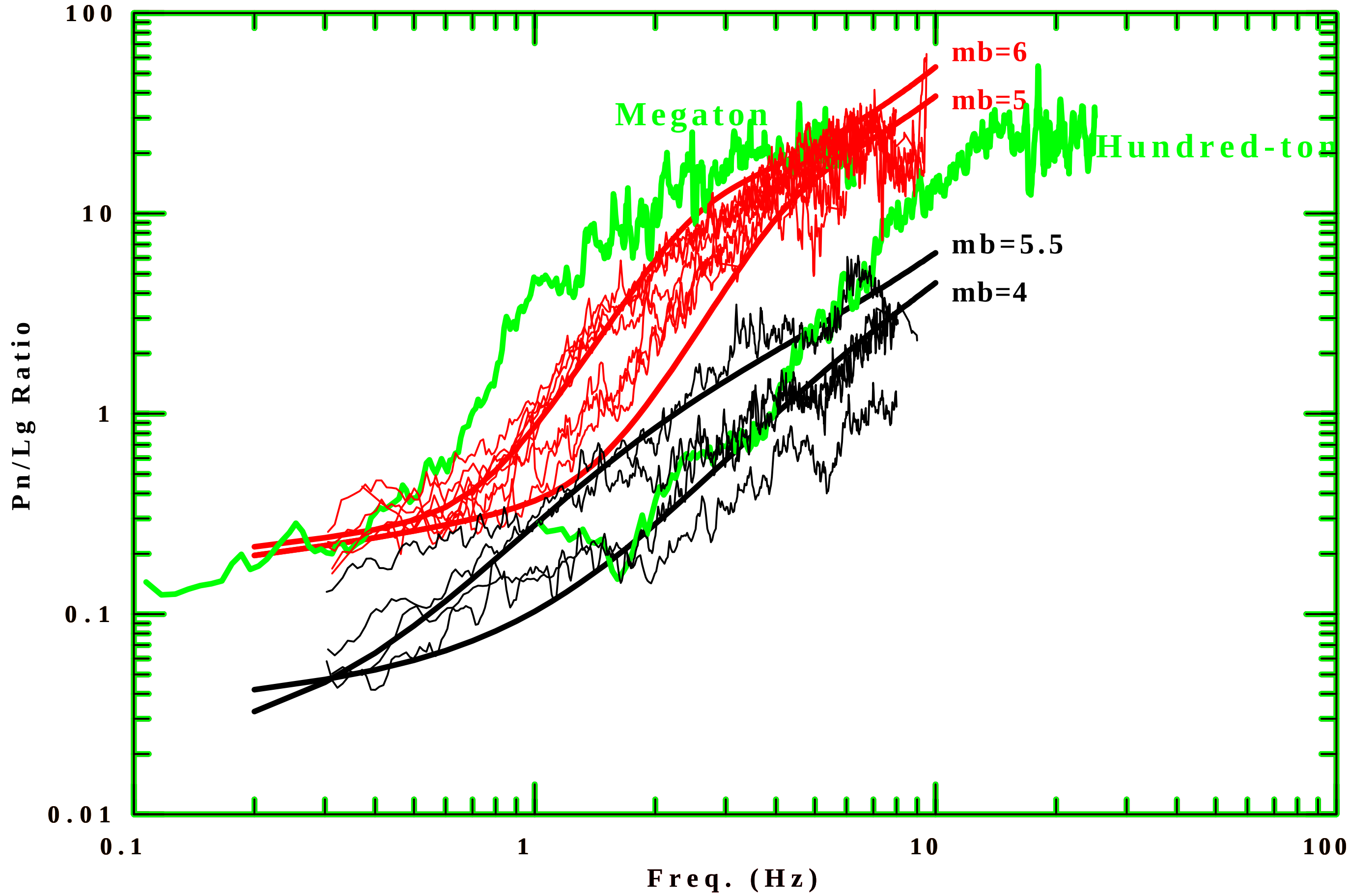

Fig. 8. Pn/Lg spectral ratios. Thick smooth curves are statistically predicted ratios using the source scaling relationships and generic path Q_{Lg} and Q_{Pn} models, for explosions with two m_b values (6 and 5) and earthquakes with two m_b values (5.5 and 4), respectively. Thin, fluctuating curves are the observed ratios for explosions and earthquakes obtained by Xie & Patton (1999, Fig. 12). Thick grey curves are observed ratios from the 052192, "megaton" and 082298, 100-ton explosions. The latter curve is corrected for its Q_{Lg} and Q_{Pn} values that differ from the generic path.